

19



Europäisches Patentamt  
European Patent Office  
Office européen des brevets

11 Publication number:

**0 297 608  
A1**

12

## EUROPEAN PATENT APPLICATION

21 Application number: 88110572.0

51 Int. Cl.4: F16F 13/00 , F16F 9/44

22 Date of filing: 01.07.88

30 Priority: 02.07.87 JP 165915/87

43 Date of publication of application:  
04.01.89 Bulletin 89/01

84 Designated Contracting States:  
DE GB

71 Applicant: NISSAN MOTOR CO., LTD.  
No.2, Takara-cho, Kanagawa-ku  
Yokohama City(JP)

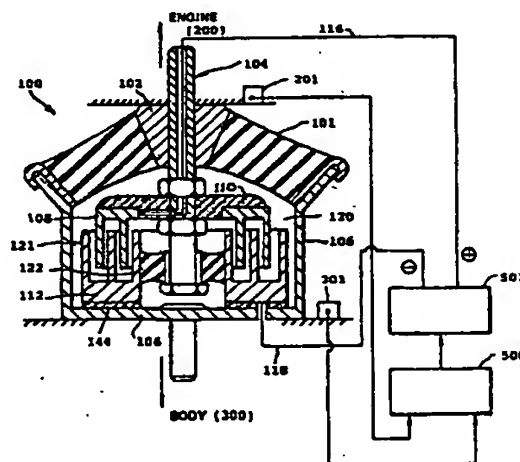
72 Inventor: Doi, Kazuhiro  
Kanayama-hatsu 203 NO. 3-36-17, Yokodai  
Isogo-ku Yokohama City(JP)  
Inventor: Fujiwara, Yasuhiko  
No. 3-5-11, Wakabadai Shiroyama-cho  
Tsukui-gun Kanagawa Prefecture(JP)  
Inventor: Abe, Toshiro  
Kosumo-mitakadai 301 No. 2-4-32, Kitano  
Mitaka City Tokyo(JP)  
Inventor: Matsui, Shinichi  
Tsukuihama-so C-2-1, No. 888  
Tsukui Yokosuka City(JP)

74 Representative: Patentanwälte Grünecker,  
Kinkeldey, Stockmair & Partner  
Maximilianstrasse 58  
D-8000 München 22(DE)

54 Electronically controllable vibration damper for use with automotive engine or the like.

57 A vibration damper (100) includes first (108) and second electrode bodies (112) which are operatively connected with a vibrating body (200) and a base (300), respectively and which are immersed in a rheopetic fluid. The relative velocity and displacement between the body (200) and the base (300) are determined and used to control the voltage applied across the electrode bodies (108, 112) in manner wherein when the relative displacement and velocity are in phase, a high voltage is applied to electrodes (100, 112) to induce a high damping force and as the period wherein the two parameters go out of phase is approached, the voltage is continuously reduced to reduce the damping force.

FIG. 2



EP 0 297 608 A1

# ELECTRONICALLY CONTROLLABLE VIBRATION DAMPER FOR USE WITH AUTOMOTIVE ENGINE OR THE LIKE

## BACKGROUND OF THE INVENTION

### Field of the Invention

The present invention relates to a liquid filled damper which can be used as an engine mount or the like and which exhibits variable damping characteristics.

### Description of the Prior Art

JP-A-60-104828 discloses an arrangement wherein damping characteristics can be switched between hard and soft under electronic control. However, this arrangement can only be switched between hard and soft modes and as a result when the exciting frequency is high the damping force component is amplified in a manner wherein it exceeds the damping effect provided by the elastomeric spring and induces the drawback that effective vibration damping cannot be achieved.

## SUMMARY OF THE INVENTION

It is an object of the present invention to provide an electronically controlled arrangement of the nature disclosed in the above prior art document and which is controllable in a manner which provides effective vibration damping.

In brief, the above object is achieved by an arrangement wherein a vibration damper includes first and second electrode bodies which are operatively connected with a vibrating body and a base, respectively and which are immersed in a rheopectic fluid.

The relative velocity and displacement between the body and the base are determined and used to control the voltage applied across the electrode bodies in a manner wherein when the relative displacement and velocity are in phase, a high voltage is applied to electrodes to induce a high damping force and as the period wherein the two parameters go out of phase is approached, the voltage is continuously reduced to reduce the damping force.

More specifically, the present invention is deemed to comprise a vibration damping arrangement disposed between a base and a vibrating body, and which is characterized by: a resilient member, said resilient member being operatively

connected between said vibrating body and said base, said resilient body acting as a spring which is compressed in response to the relative displacement between said vibrating body and said base; a housing associated with said spring; first and second electrode bodies disposed in said housing, said first and second electrode bodies being immersed in a fluid having rheopectic properties and the viscosity of which changes with the voltage applied across said first and second electrode bodies, said first and second bodies being arranged to be movable relative to one and other and to define in combination with said rheopectic fluid, a variable damping device; a sensor arrangement for sensing a parameter which varies with vibration of said vibrating body; a control circuit which is responsive to said sensor for determining the relative velocity and the relative displacement of said vibrating body with respect to said base, said control circuit being arranged to control the voltage applied to said first and second electrode bodies in a manner which reduces the damping effect provided by said variable damping device when the relative displacement and the relative velocity are in phase and which increases the damping effect when the relative displacement and the relative velocity are out of phase.

## BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows in schematic form the arrangement which characterizes the present invention;

Fig. 2 is a sectional elevation of an embodiment of the present invention;

Fig. 3 is a flow chart-like block diagram which shows the steps executed by a algorithm which forms a vital part of the present invention;

Fig. 4 is schematic diagram which illustrates the arrangement of the engine with respect to the vehicle chassis and the mode in which vibration is transmitted;

Fig. 5 is a chart defined in terms of force and time which depicts the basic interaction of the forces which are transmitted by the elastomeric spring and the fluid damping arrangements;

Fig. 6 is a timing chart which shows the operational characteristics derived with the above discussed prior art; and

Fig. 7 is a timing chart similar to that shown in Fig. 6 and which shows the control and operational characteristics provided by the instant invention.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Figs. 1 and 2 shows the construction and arrangement of an embodiment of the instant invention. In this arrangement a damper unit generally denoted by the numeral 100 is arranged to support an engine or similar body 200 which is subject to vibration on a vehicle chassis or the like base 300.

The damper unit in this instance includes an elastomeric body 101 (rubber) which acts as a spring. The body 101 is secured to the engine 200 through an upper connector member 102 through which a shaft 104 passes. The upper connector member 102 and the shaft 104 are rigidly connected to the engine 200 in a manner to be vibratable therewith. The outer periphery of the elastomeric body 101 is arranged to seat in and be hermetically connected to the mouth of a cup-like container 106 which is secured to the body 300.

A first electrode body 108 is supported on the shaft 104 and insulated therefrom by a first insulating member 110. A second electrode body 112 is mounted on the bottom of the cup-like member 106 through a second insulating member 114. A first lead line 116 is arranged to pass through a hollow section of the shaft 101 and the first insulating body 110 and to be electrically connected to the first electrode body 108. A second lead line 118 is arranged to pass through concentrically arranged apertures which are formed in the bottom of the cup-like housing 106 and insulating member 114 and be connected to the second electrode body 112.

In this embodiment the first and second electrode bodies include a plurality of concentric annular rib-like projections (no numerals) which are interleaved in the illustrated manner. This of course defines two relatively large and closely juxtaposed surface areas between which a potential can be developed.

The chamber 120 defined within the cup-like member 106 by the elastomeric body 101 is filled with a fluid which exhibits rheopectic properties and which becomes more viscous upon the application of a voltage across the first and second electrode bodies 108, 112 (Winslow effect). The combination of the first and second electrode bodies 108, 112 and the rheopectic fluid define a variable damping arrangement which is generally denoted by the numeral 121.

The lower end of the shaft 104 is connected to the second electrode body 112 through a flat annular elastomeric body 122.

This body exerts a centering action on the two electrode bodies 108, 112 and ensures that the two remain in a non-contacting relationship with one and other even when subjected to strong vibration.

Sensors 201 and 301 are respectively mounted on the engine and the body and arranged to be responsive to the vertical vibration of the same. The outputs of the sensors are supplied to a control circuit 500. In this instance the control circuit includes a microprocessor in which a suitable algorithm for processing the data inputs and for producing a control signal which is applied to a power source 501, is stored. This power source 501 is connected to the first and second electrode bodies 108, 112 by way of the first and second lead lines 116, 118.

The operations performed by the algorithm are depicted in Fig. 3. As shown, the outputs of the two sensors are fed to the interface (not illustrated) of the microprocessor are each subject to a first integration. The resulting velocity values are subtracted in a manner which derives a relative velocity value  $\dot{X} - \dot{X}_0$ . Each of the velocity values are then again subject to integration in manner to derive displacement values  $X$  and  $X_0$ . These values are subject to subtraction in a manner which produces a relative displacement value  $(X - X_0)$ .

The input of sensor 201 is monitored and a count indicative of the vibration frequency developed. The period of the vibration is derived and set in RAM for later use.

The relative velocity value  $(\dot{X} - \dot{X}_0)$  is used in combination with the damping coefficient  $C$  in a manner to derive a damping force  $F_c$ : viz.,

$$F_c = C \times (\dot{X} - \dot{X}_0) \quad (1)$$

while the relative displacement value  $(X - X_0)$  is used in combination with the spring constant  $K$  to derive a Spring force  $F_k$ : viz.,

$$F_k = K \times (X - X_0) \quad (2)$$

The relative velocity value and the relative displacement value are multiplied and compared to determine if the product is greater or less than zero. In the event that the outcome is greater than or equal to zero it is indicated that the spring force  $F_k$  and the damping force  $F_c$  are in phase while when the value is less than zero  $F_k$  and  $F_c$  are indicated as being out of phase (in reversed phases).

In the event that the comparison reveals that the just mentioned product is greater than zero then the count of a counter  $P$  is set to zero and the voltage to be applied is set to a low value  $V_2$  which induces a correspondingly low damping coefficient having a value of  $C_2$ .

However, in the event the outcome of the first comparison indicates a value which is less than zero, then the algorithm proceeds to execute a second comparison wherein the instant values  $F_c$  and  $F_k$  values are compared. In the event that  $F_k$  is greater or equal to  $F_c$  then the count of counter  $P$  is incrementally increased by one and the voltage to be applied is set at a value of  $V_1$  (which induces

a damping coefficient having a value C1). At this time sampling time ( $\Delta t$ ) and the count value of P on the previous run are obtained and temporarily set in memory.

In the event that  $F_k$  is larger than  $F_c$  the the program proceeds to perform calculations which develop values for variables Z and Q using the following equations:

$$Z = (V1 - V2)/(\text{PERIOD} - P \Delta t) \quad (3)$$

and

$$Q = Q + \Delta t \quad (4)$$

Following the derivation of this data the voltage to be applied to the electrode bodies is calculated

$$V3 = V1 - Z \cdot Q \quad (5)$$

As will be appreciated, until the first comparison again indicates a positive outcome the level of the voltage applied to the electrode bodies is continuously reduced. Upon the outcome becoming positive the count of P is returned to zero.

The operation of the above described arrangement is such that when the engine is idling the forces which are applied from the vibrating body (engine) to the stationary one or base in the manner shown in Fig. 4

As shown in Fig. 5 when:

to  $< t < T$  and

To  $+ (T/2) < t < to$

then  $F_k$  and  $F_c$  are in phase. However, when:

to  $+ (T/4) < t < to + (T/2)$  and

to  $+ (3T/4) < t < to + T$

then  $F_k$  and  $F_c$  are out of phase.

Thus, as will be seen while the two are in phase the damping force  $F_c$  reduces from a peak value, while during the reversed phase period  $F_c$  increases towards its peak value. Accordingly, by controlling the manner and the level to which  $F_c$  increases, it is possible to variably control the F total force.

As shown in Fig. 6, when  $F_c$  is controlled in a purely digital type ON-OFF manner, the damping force control is only switched between high and low modes. Accordingly, as pointed out in the opening paragraphs of the instant disclosure, this leads to the situation wherein, during the high damping reversed phase period, the damping force  $F_c$  becomes notably greater than the spring force  $F_k$  and, as shown in hatching, a spike is produced in the transmission power wave and the attenuation provided by the transmitted force F total, is reduced.

In comparison, with the present invention as evident from Fig. 7, during the reversed phase period, as the voltage signal which is applied to the electrode bodies 108, 112 is variably controlled in a manner wherein, during the generation of a high damping force, the level thereof is continuously reduced from time points  $t_1$  and  $t_2$  (by way of example), a corresponding reduction in damping

force  $F_c$  is induced.

This, as demonstrated in Fig. 7, is such as to eliminate the spike formation in the transmission power wave and thus improve the damping characteristics of the device under such circumstances.

The arrangement of the present invention is such as to provide the following benefits.

1. During the reversed phase period until the the damping force  $F_c$  and the spring force  $F_k$  become equal a high damping force is produced. Further, from said time the damping force is switched to a low value. This sequence of damping control is such that vibration over a wide frequency can be attenuated.

2. When the present invention is applied to engine mounts, the idle frequency which tends to be transmitted to the vehicle chassis and induce the generation of cabin reverberation noise can be reduced in a manner which greatly improves the noise levels in the vehicle cabin.

The present invention is not limited to the illustrated type of arrangement can the concept on which the invention is based used in other devices without departing from the scope of the present invention. For example, the above described electronic control can be applied with similar advantage to suspension shock absorbers if so desired.

Alternatively, in place of sensing the vibration it is possible in the case of automotive applications use the engine speed as a control parameter in that the engine vibration is related to the engine rotational speed, number of cylinders and the like.

## Claims

1. A vibration damping arrangement disposed between a base and a vibrating body, said damper arrangement comprising:

a resilient member, said resilient member being operatively connected between said vibrating body and said base, said resilient body acting as a spring which is compressed in response to the relative displacement between said vibrating body and said base;

a housing associated with said spring;

first and second electrode bodies disposed in said housing, said first and second electrode bodies being immersed in a fluid having rheopectic properties and the viscosity of which changes with the voltage applied across said first and second electrode bodies, said first and second bodies being arranged to be movable relative to one and other and to define in combination with said rheopectic fluid, a variable damping device;

a sensor arrangement for sensing a parameter which varies with vibration of said vibrating body;

a control circuit which is responsive to said

sensor for determining the relative velocity and the relative displacement of said vibrating body with respect to said base, said control circuit being arranged to control the voltage applied to said first and second electrode bodies in a manner which reduces the damping effect provided by said variable damping device when the relative displacement and the relative velocity are in phase and which increases the damping effect when the relative displacement and the relative velocity are out of phase.

2. A vibration damping arrangement as claimed in claim 1 wherein:

said first electrode body is rigidly and insulatingly connected to said vibrating body; and  
said second electrode body is rigidly and insulatingly connected with said base.

3. A vibration damping arrangement as claimed in claim 2 wherein said first and second electrode bodies include structures which are interleaved.

4. A vibration damping arrangement as claimed in claim 3, wherein said spring comprises a first elastomeric body which is disposed in an opening formed in said housing.

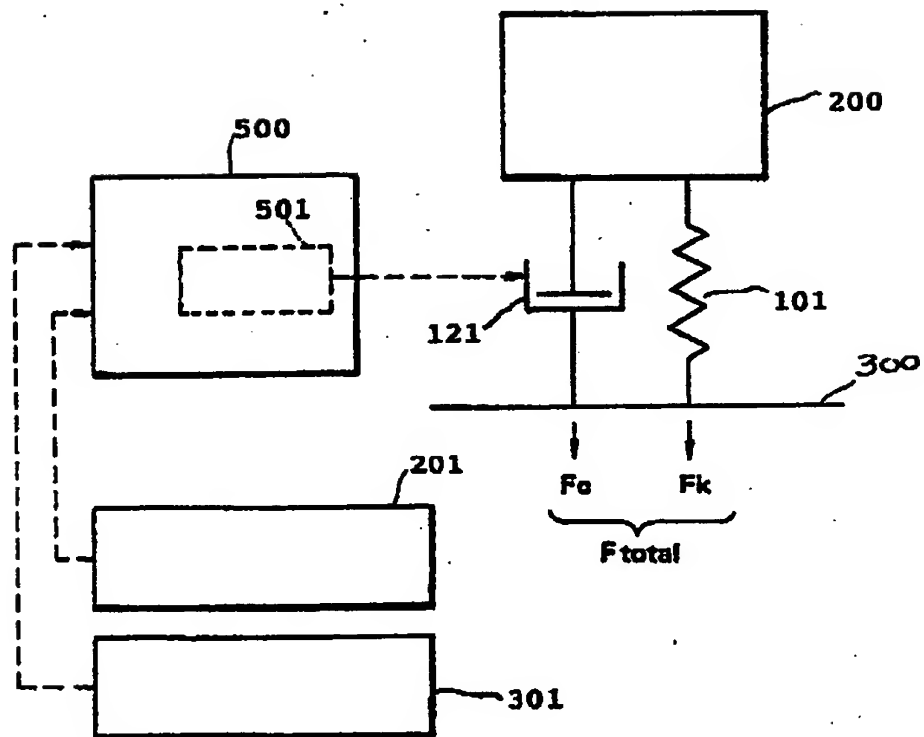
5. A vibration damping arrangement as claimed in claim 1 wherein said sensor arrangement includes;

a first sensor for sensing the acceleration of said vibrating body; and

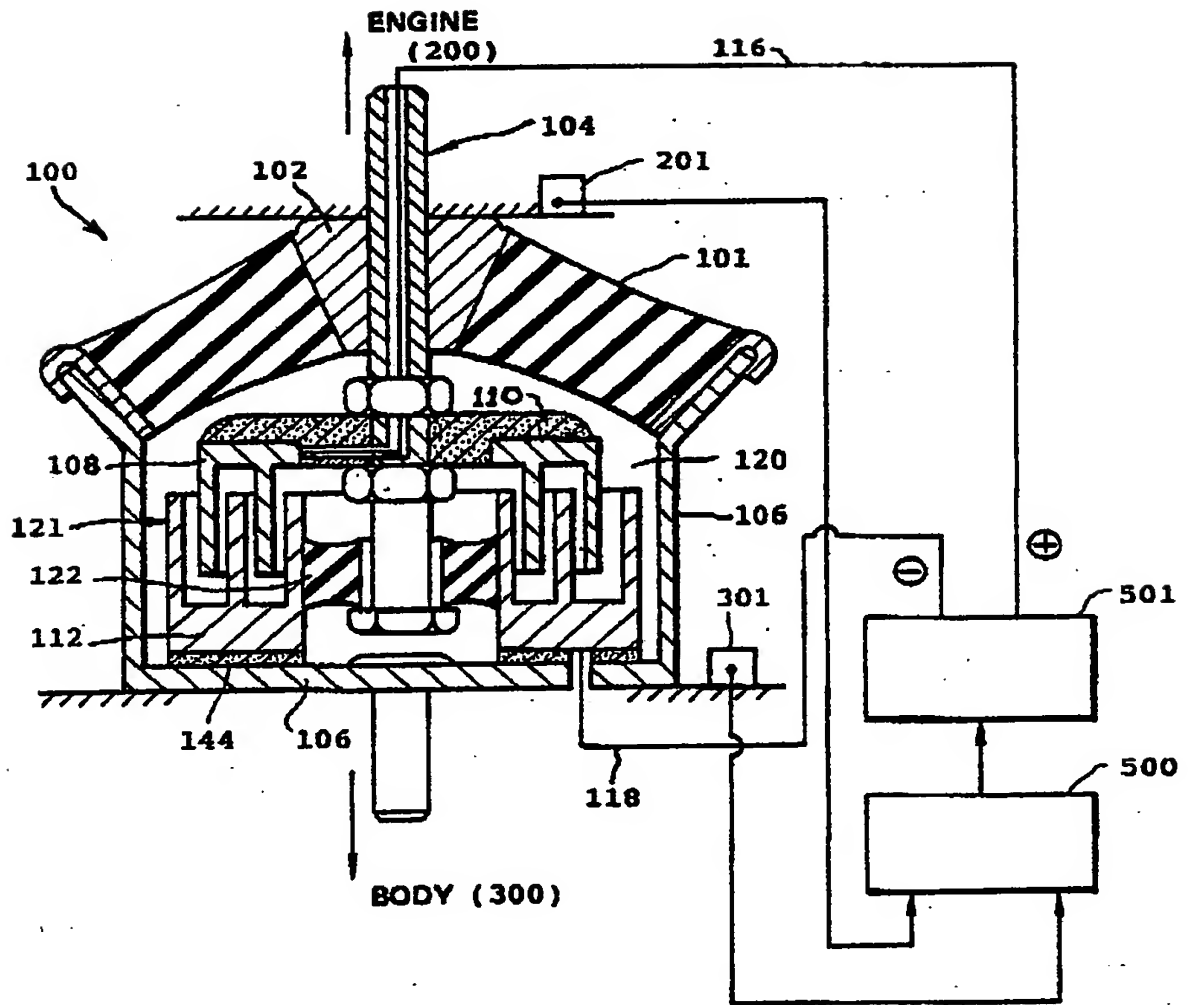
a second sensor for sensing the acceleration of said base.

6. A vibration damping arrangement as claimed in claim 1 wherein the control circuit continuously reduces the voltage applied to said first and second electrode bodies from the time the level of the damping force produced by the variable damping device exceeds the level of the spring force produced by the elastomeric body subsequent to the combination of the damping force and spring force produced by said elastomeric body assuming a zero value during the period the relative displacement and the relative velocity are out of phase.

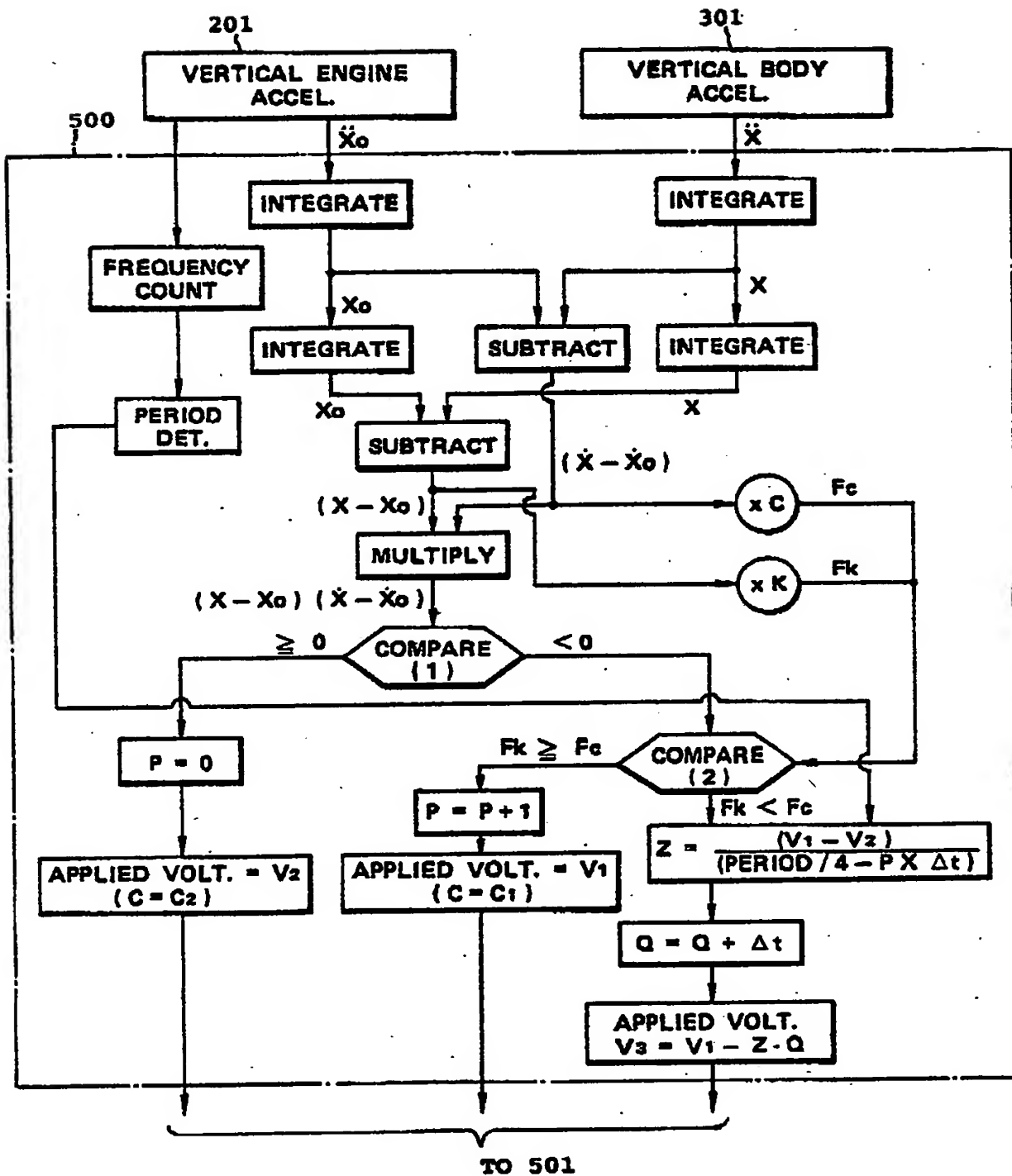
**FIG.1**



**FIG. 2**

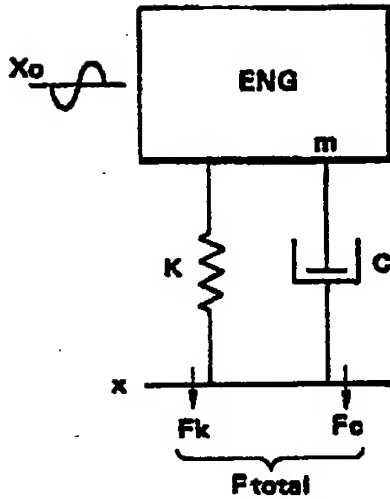


PAGE 19/21

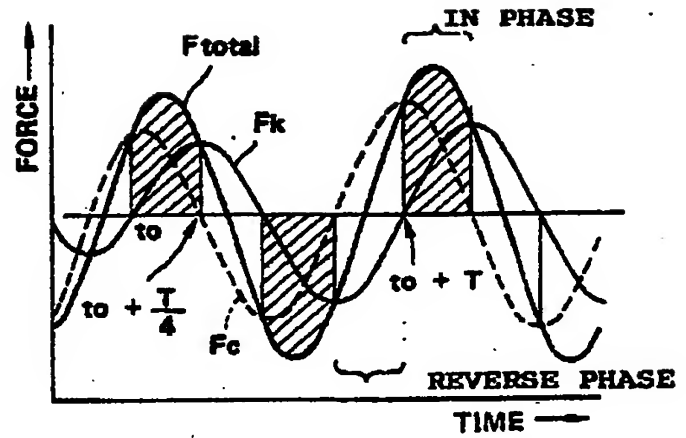




**FIG. 4**



**FIG. 5**



**FIG. 7**

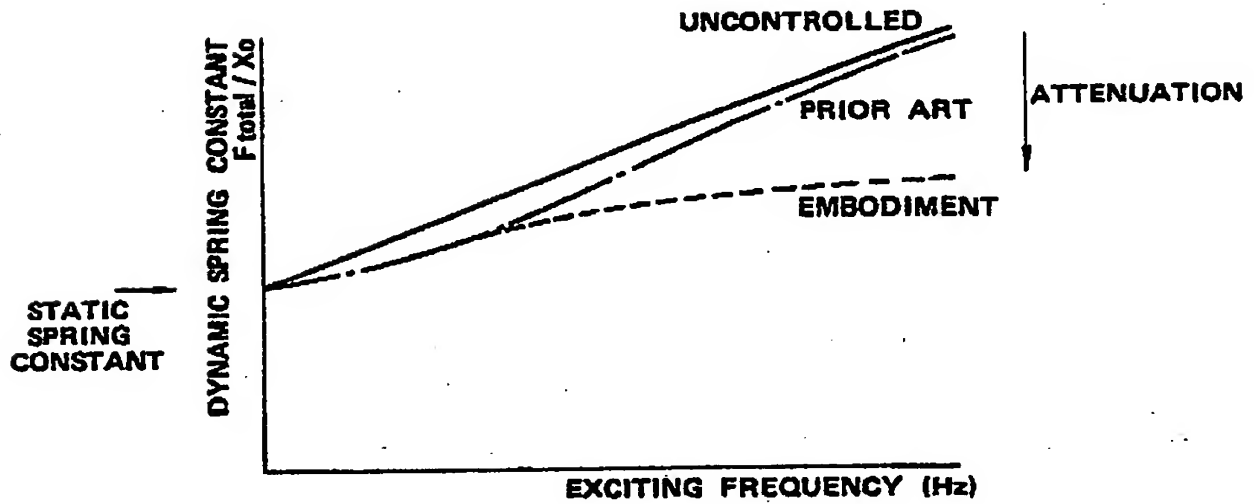
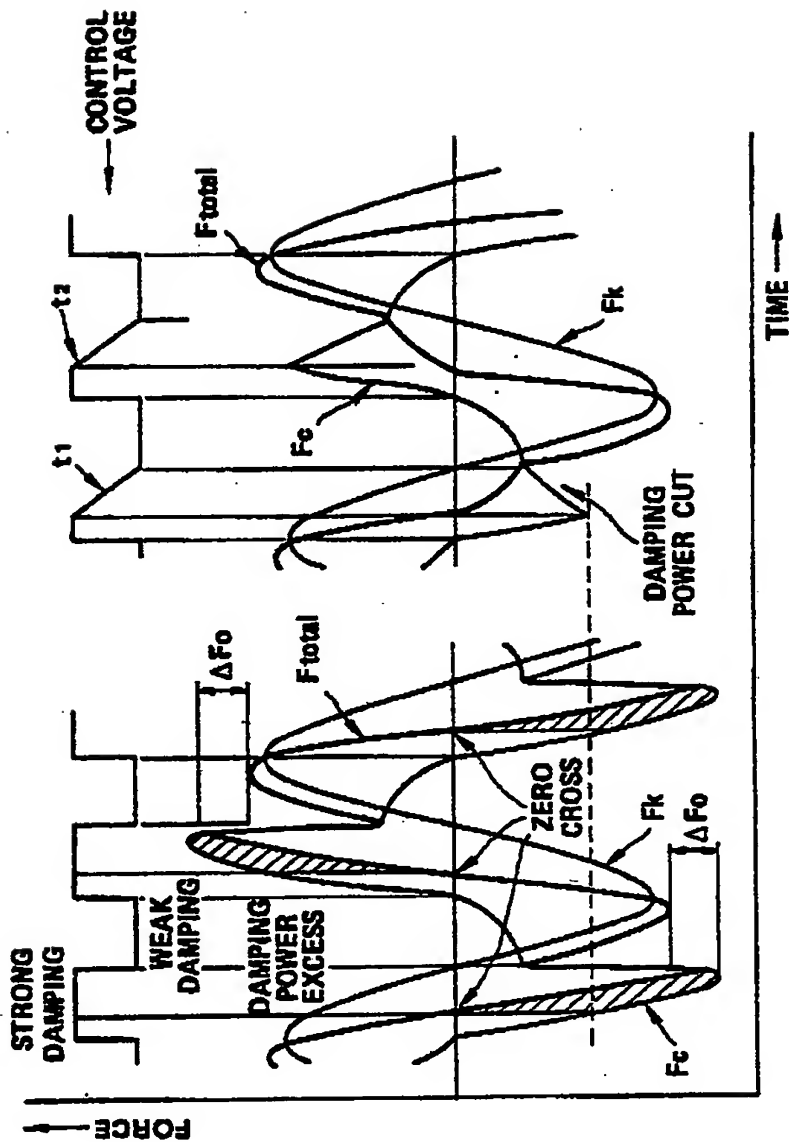


FIG. 6





European Patent  
Office

# EUROPEAN SEARCH REPORT

Application Number

EP 88 11 0572

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 4)
Y	EP-A-0 209 145 (METZELER KAUTSCHUK GmbH) * Claims 1-7; figure 1 *	1	F 16 F 13/00 F 16 F 9/44
A	* Page 6, lines 20-26 *	2-4	
Y	EP-A-0 183 039 (ROBERT BOSCH GmbH) * Page 5, line 23 - page 6, line 26; claims 1,10; figures 1-5 *	1	
A		5	
A	DE-A-3 433 797 (UNI-CARDAN AG) * Claims 1,24-27; figure 8 *	1,3-5	
			TECHNICAL FIELDS SEARCHED (Int. Cl. 4)
			F 16 F
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 05-10-1988	Examiner SINGER G.M.
CATEGORY OF CITED DOCUMENTS			
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons A : member of the same patent family, corresponding document	